High Frequency Acoustic Propagation in Littoral and Surf Zone Environment: The Analysis of Temporal Fluctuations and Development of Adaptive Signal Processing Algorithms

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LONG-TERM GOALS

There are three long term goals of this work. The first is to the characterize features of high frequency acoustic propagation in shallow water that are relevant to the performance and design of acoustic communications systems. The second is to develop closed form expressions for the performance of channel identification and acoustic communications algorithms as a function of environmental conditions. The final goal is to develop improved channel estimation and demodulation algorithms for phase coherent acoustic communications in this environment.

OBJECTIVES

There are four primary scientific objectives of this effort. The first of these is to characterize the acoustic channel fluctuations (e.g., deterministic structure, rate of fluctuation, intensity variability) of surface scattered arrivals caused by surface wave focusing. The goal is relate these characteristics to the propagation geometry, surface wave characteristics, and the orientation with respect to the surface wave field.

The second scientific objective is to characterize the impact of sea surface state, the presence or absence of subsurface bubbles, source to receiver range, and orientation with respect to the surface wave field on the delay and path specific Doppler spread of the acoustic channel impulse response.

The fourth scientific objective is to improve upon previously developed closed form expressions for the soft decision error achieved by a channel estimate decision feedback equalizer (CE-DFE) and relate this error to environmental conditions.

The final scientific objective is to develop improved methods of estimating the channel impulse response.

APPROACH

The approach taken to achieving the first two scientific objectives is to combine the gathering and analysis of field data with the analytical modeling of acoustic propagation and scattering. This work is a collaborative effort between myself and Dr. Grant Deane (Scripps Institution of Oceanography). The gathering and analysis of the field data involves serveral steps. These include carrying out a surface wave focusing experiment in the surf zone environment, estimating the time varying impulse

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14. ABSTRACT

There are three long term goals of this work. The first is to the characterize features of high frequency acoustic propagation in shallow water that are relevant to the performance and design of acoustic communications systems. The second is to develop closed form expressions for the performance of channel identification and acoustic communications algorithms as a function of environmental conditions. The final goal is to develop improved channel estimation and demodulation algorithms for phase coherent acoustic communications in this environment.

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response of the acoustic channel from the data that is gathered and a deterministic reconciliation between the estimates and the results of modeling this impulse response using the Wavefronts acoustic propagation model developed by Prof. Chris Tindle (University of Auckland). Other aspects of the work include the development of a geometric optics approach for modeling the surface scattered arrival structure in a fully 3-D propagation environment and the use of the geometric optics approach to calculating the Dopper spreading of surface scattered arrivals. The work also involved the analysis of data from the SPACE02 experiment including analysis of ambient noise characteristics as well as the dynamics of the channel impulse response.

The approach to achieving the last two scientific objectives is though the direct derivation of the equations describing the channel estimation and soft decision errors and the modeling of the channel estimation error as contributing to an effective observation noise.
work at your own or other organizations and the roles they play.

WORK COMPLETED

The work on characterizing the performance of channel estimate equalizers (MMSE linear, passive time revsersal, and MMSE CE-DFE) has been completed and a paper writing, submitted and published. Analaysis of data from the Wavefronts II experiment and the SPACE02 experiment has continued with emphasis on characterizing the time variation of the acoustic channel. The data has also been used to test new channel estimation algorithms. The Wavefronts V experiment was planned and deployed off of Scripps Pier (headed by Grant Deane) in February and March, 2005. Significant progress has been made on the development and analysis of channel estimation algorithms for rapidly time varying and sparse channels.

RESULTS

We learn the limitations of the WSSUS assumption in characterizing equalizer performance using channel scattering functions. This motivates the use of more realistic assumptions regarding channel variation (see the JASA, July 2005 paper). We have new experimental evidence that the time variability of acoustic channels can become less severe as range increases indicating that acoustic communications systems performance may actually improve with increased range up to a limit. (See the enclosed figure). This result is very new and unpublished. We have formulated "persistence of excitation" requirements for joint parameter/state estimators (an example is a channel estimation algorithm that simultaneously estimates the channel impulse response and parameters representing the channel variability) that given insight into why traditions Extended Kalman Filter (EKF) and Estimate Maximize (EM) algorithms are unable to reliably track some underwater acoustic channel impulse responses (the data on which this has been tested is from
the Wavefronts III experiment and is applicable to very shallow water channels).
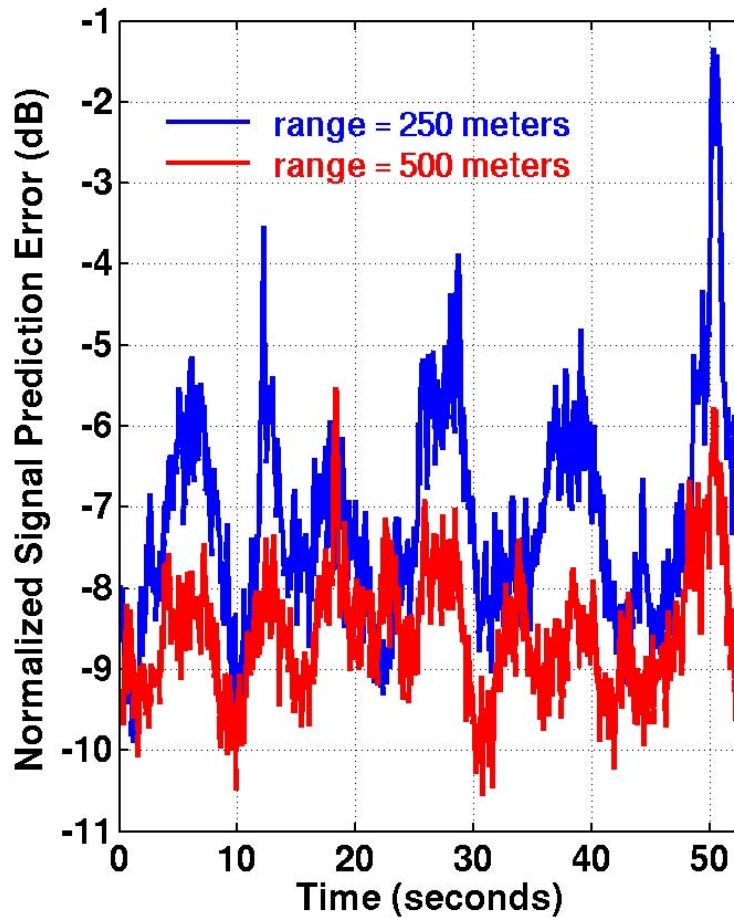
The normalized signal prediction error as a function of time for a RLS estimator tracking the channel impulse response during a 52second transmission during the SPACE02 experiment. A highererror indicates that the algorithm is doing a poorer job of trackingthe channel impulse response. The short range (250 meter)results show a higher error than those for the longer range (500 meter)ehannel. This is particularly true for the times of rapid channel fluctuations when both the performance at both ranges degrades.

IMPACT/APPLICATIONS

The formulation of the techniques for predicting equalizer performance and understanding the limitations of various techniques will be very useful in the optimization of network topologies for underwater acoustic communications networks. The results on characterizing channel variability will be similarly important for network optimization in addition to new algorithm development, particularly for shallow and very shallow water environments where surface scattered signals are an important component of the received signal. The persistence of excitation results have motivated the development of a new class of channel estimation algorithm for short range channels.

TRANSITIONS

The performance prediction and channel characterization results will be transitioned to the PLUSNet program as part of the Field and Network Control tasks.

RELATED PROJECTS

The PLUSNet and AOFNC programs are related projects that will use the results of this work.

PUBLICATIONS

J. Preisig, ``Performance analysis of adaptive equalization for coherent acoustic communications in the time-varying ocean environment'', JASA, Vol. 118, July 2005, pp. 263-278. [published, refereed]

W. Li, J. Preisig ``Vector Form EM and Suboptimal Joint State and Parameter Estimation'' in Proceedings ICASSP 2006, Philadelphia, PA, March 19 - 23, 2005, Vol 4, pp.~313 - 316. [published, refereed conference]